Malaysian Journal of Medicine and Health Sciences (eISSN 2636-9346)

ORIGINAL ARTICLE

A Phantom-based Investigation Into the Influence of Low Tube Potential and Matrix Size on Radiation Dose and Image Quality for a 128 Slice Abdominopelvic Ct Protocol

Nitika C. Panakkal[1], Rajagopal Kadavigere[2], Suresh Sukumar[1], Ravishankar N[3]

[1] Department of Medical Imaging technology, Manipal College of Health Professions, Manipal Academy of Higher Education, Manipal, Karnataka, India
[2] Department of Radio diagnosis & Medical Imaging, Kasturba Medical College, Manipal Academy of Higher Education, Manipal, Karnataka, India
[3] Department of Biostatistics, Vallabhbhai Patel Chest Institute, University of Delhi, India

ABSTRACT

Introduction: Reducing radiation dose for CT examinations has been accompanied by an increase in image noise. Studies have highlighted the application of a higher matrix size for improving image quality when assessing the lungs. This study aims to evaluate the influence of a low kVp and higher matrix size on radiation dose and image quality for abdominopelvic CT. **Methods:** This experiment was done on a 32 cm body phantom and scanned using a 128 slice CT scanner. The study utilised various combinations of kVp settings (140, 120, 100, 80 & 70) and matrix sizes (1024, 768 & 512). The image obtained was analysed objectively and subjectively. For objective analysis, we calculated SNR, and CNR. For subjective analysis, two radiologists evaluated the image in a 3-point scoring scale. **Results:** The study reported an increase in SNR (0.8%) and CNR (46%) at 120 kVp when increasing the matrix size from 512 x 512 to 768 x 768. Similarly, there was an increase of 14.5 % and 56.4 % in CNR and SNR using 1024 matrix size. The DLP was reduced by 4.5%, 50% and 70.6 % using 100, 80 and 70 kVp respectively. However, there was no change in DLP with higher matrix sizes. **Conclusion:** The study reported a combination of 100 kVp and 768 matrix size resulted in an almost similar (↓0.9 %) SNR and improved CNR (↑46.4 %) compared to 120 kVp and 512 matrix size. Qualitative analysis also showed a similar image quality with decreased radiation dose for abdominopelvic CT.

Keywords: Image matrix, Radiation dose, Image quality, Abdominopelvic CT, Dose length product (DLP)

Corresponding Author:
Rajagopal Kadavigere, MD
Email: rajarad@gmail.com; rajagopal.kv@manipal.edu
Tel: +91 9448158901

INTRODUCTION

Computed tomography (CT) is a necessary diagnostic equipment that constructs cross-sectional images to identify various pathologies in different areas of the body. In the United States, an estimate of around 62 million people undergo CT scans per year (1). There is a dramatic increase in CT scans due to the rapid advances in imaging technology such as faster scan times, advanced multi-planar reconstruction techniques, reduced artifacts, improved contrast, spatial and temporal resolution (2-4). Compared to conventional X-ray examinations, CT alone involves larger radiation doses with a more significant dose obtained from thorax and abdominopelvic CT scans (1, 5-7).

The frequency of abdominal CT examinations have increased due the extensive use of multi-detector row CT scanners. Despite its advantages in imaging, radiation exposure is a cause of concern. Contrast studies of the CT abdominopelvic scan have a greater radiation exposure due to the multiphase abdominal protocols. The cause of concern, although controversial, is the risk to develop cancer induced by radiation from CT examinations (1,8).

To decrease radiation dose, the International Commission on Radiological Protection proposed principles on radiation safety which includes justification, optimisation and developing dose limits. The dose in CT can be measured by evaluating the dose length product (DLP). The dose length product is used to calculate dose for a series of scan and takes into account the scan length and the average dose in x,y and z axis (CTDI vol).

In CT, radiation dose can be minimised by selecting proper scan volume and adjusting scan parameters like pitch, rotation time, slice width, slice gap. Tailored exposure parameters like kVp, mAs and usage of dose modulation techniques also play an important role in reducing dose. The automated dose modulation has reported to reduce the dose by 20-50 % (9,10). However, trying to decrease the dose can upturn the noise in an image and therefore worsen the quality of the image. In these cases, the introduction of iterative reconstruction is very beneficial as they are capable of producing optimal reconstructed images with limited sets of projections, thereby making it possible to reduce dose without degrading the quality of the image.

Image quality in CT is influenced by noise, artifacts, contrast and spatial resolution. The noise and contrast can be measured objectively by calculating the Signal to noise ratio (SNR) and Contrast to noise ratio (CNR). The SNR is a ratio of the desired signal to noise and CNR is a measure of contrast between the area of interest to that of background. Spatial resolution is beneficial to distinguish smaller structures in closer proximity. Spatial resolution in CT depends on the focal spot size, detector size, reconstruction algorithms and image matrix.

The 512 x 512 matrix size has been the standard for almost all CT studies (11). Bigger image matrix such as 1024 x 1024 and 2048 x 2048 that are commercially available in ultra- high resolution computed tomography (HRCT) are reported to improve the diagnostic quality of image for assessing lung diseases (12). However, there is a lack of research that focus on the effect of matrix size on image quality in abdominopelvic CT. Therefore, the main objective of the study is to test if an increase in matrix size improve the image quality. Secondly to evaluate the influence of low kilo-voltage and matrix size on radiation dose and image quality respectively for abdominopelvic computed tomography.

MATERIALS AND METHODS

This experiment was carried out in a 32 cm body CT PMMA phantom to simulate a human abdomen and pelvis and scanned using a 128 slice Philips Incisive CT scanner. The scanner underwent routine air calibration prior to the scan as per manufacture recommendation. The phantom was set down supinated in the CT table with isocentre fixed at center of the phantom. The height of the phantom was adjusted using the coronal laser light. The current study was performed at 5 different kVp setting (140, 120, 100, 80 & 70) and three matrix sizes (1024, 768 & 512) with iterative reconstruction of iDose4, level 3. Images acquired using 120 kVp and 512 x 512 matrix size was considered as reference images. The various combinations of kVp and matrix size included were 120 kVp with 768 x 768 & 1024 x 1024 matrix size, 100 kVp with 512 x 512, 768 x 768 & 1024 x 1024 matrix size, 80 kVp with 512 x 512, 768 x 768 & 1024 x 1024 matrix size & 70 kVp with 512 x 512, 768 x 768 & 1024 x 1024 matrix size. All scans were performed utilising automatic longitudinal tube current modulation.The following CT scan parameters were maintained for all scans: Pitch of 1, 0.5 s rotation time, detector collimation of 64 *0.625 mm, 5 mm slice thickness; 350 mm field-of-view (FOV) and 105 mm scan length. The Axial 2D CT image obtained was analysed for radiation dose and image quality. The quality of the image was assessed both objectively and subjectively.

Quantitative analysis

Objective image assessment was done by determining the signal to noise ratio (SNR) and contrast to noise (CNR) ratio. For this purpose, a region-of-interest (ROIs) of 200 mm2 were manually positioned in 3 regions of the phantom and background to encompass homogeneity of measured tissues. The following equation was utilized to assess the SNR and CNR ratios.

SNR = (CTROI) / SDROI
CTROI- CT number of Region of interest
SDROI- standard deviation of Region of interest
(13)

CNR = (CT ROI – CT Background) / SD Background

CTROI- CT number of Region of interest (13)
CT background- CT number of background
SD Background- Standard deviation of background

Qualitative analysis

For subjective analysis of image, two radiologists with more than ten years of experience evaluated the image once for “overall image quality”, “Image noise” and “streak artifacts” (12) on a three-point rating scale with 1,2 and 3 indicating poor, almost the same and better. The radiologists were blinded to the different combinations of matrix size and kVp. All the combinations of matrix size and kVp were compared to the reference 120 kVp and 512 x 512 matrix size. The radiologists assessed a total of 14 images independently.

Radiation dose

Dose length product for each scan was obtained from the CT console and used to assess the radiation dose.

Statistical analysis

Data was analysed using SPSS 26. Cohen’s Kappa test was performed to analyse inter-observer agreement. A Kappa value less than 0.20 pointed out poorest agreement. Values between 0.21-0.40 showed Slight agreement. Values between 0.41-0.60 and 0.61-0.80 indicated moderate and good agreement respectively. All values between 0.81-1 showed almost perfect agreement (14).

RESULTS

Radiation dose

The study results showed 4.8% decrease in DLP (437.9

mGy.cm) using 140 kVp when compared to 120 kVp (460.06 mGy.cm). Further decreasing the kVp to 100, 80 and 70 resulted in a decrease in DLP 4.5 % , 52 % and 70.6 % respectively (Table I).

Table 1: SNR, CNR and DLP for various combinations of kVp and matrix size

kVp	mA and mAs	Matrix size	SNR	CNR	DLP (mGy.cm)
140	268(122)	512	13.7	205.1	437.9
		768	13.1	194.6	
		1024	10.9	153.2	
120	409(186)	512	11.17	116.1	460.06
		768	11.26	170.9	
		1024	12.8	181.6	
100	636 (289)	512	12.2	155.5	439.28
		768	11.01	170.1	
		1024	11.41	108.6	
80	636 (289)	512	6.3	88.3	219.13
		768	5.7	94.4	
		1024	5.5	116.4	
70	636 (289)	512	3	56	135.23

Image Quality-Quantitative analysis

Using a kVp of 140 and 512 matrix size showed the highest value of SNR (13.7) and CNR (205.1). The SNR and CNR for routine abdominal and pelvis protocol (120 kVp and 512 x 512 matrix size) were 11.17 and 116.1, respectively. Table I shows the changes in DLP and image quality parameters (SNR and CNR) with a shift in kVp and matrix size. As noted in table I, there is a reduction in CNR and SNR using 70 and 80 kVp compared to the standard 120 kVp and 512 x 512 matrix size. However, using a lower kVp of 100 and a larger matrix size of 768 x 768 showed a better CNR and similar SNR with decreased radiation dose. Similarly, a combination of 140 kVp with 768 x 768 matrix size and also showed a better CNR and SNR with decreased radiation dose as depicted in the line graph. (Fig.1.).

Qualitative analysis

Two radiologists evaluated the images independently in a blinded manner on a three point rating scale. Image-analysis was done for "overall image quality", "image noise" and "streak artifacts". The scores of 120 kVp with 768 x 768 matrix size were found to be better than 120 kVp and 512 x 512 matrix size for "overall image quality" and "image noise". Streak-artifacts was graded 2 indicating identical image quality compared to the routine 120 kVp and 512 x 512 matrix size. Similarly, a combination of 100 kVp with 768 x 768 matrix size was graded two, indicating almost the same image quality compared to 120 kVp and 512 x 512 matrix size for all categories (fig.2.). A combination of 140 kVp with 512 x 512 matrix size also graded 2 indicating almost

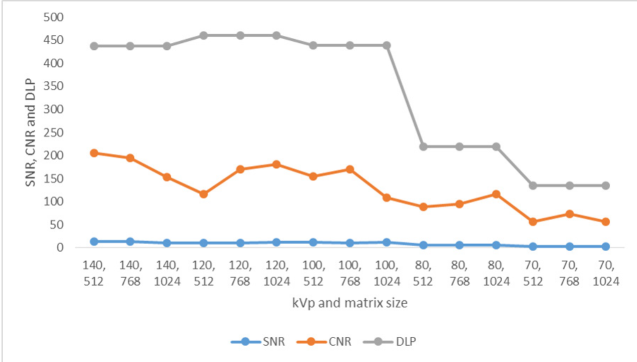

Figure 1: Line graph showing the variation in SNR, CNR and dose length product (DLP) using various combinations of kVp and matrix size

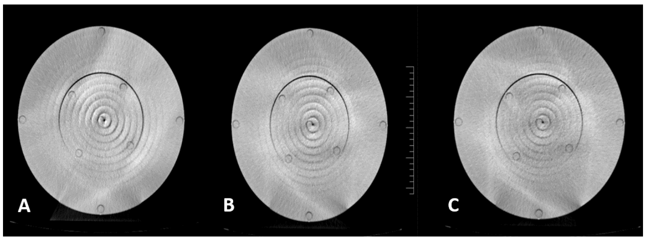

Figure 2: Phantom images obtained using various kVp and matrix size. A- 120 kVp and 512 matriz size, B- 120 kVp and 768 matrix size, C- 100 kVp and 768 matrix size

similar quality to 120 kVp and 512 x 512 matrix size for image noise and streak artifacts. All 70 and 80 kVp images were graded 1, indicating poor quality compared to the reference image. The inter-observer agreement was good in terms of overall image quality and streak artifacts (κ = 0.72; κ =0.696) and excellent in terms of image noise (κ=0.874). The inter-observer agreement for "overall image quality", "image noise" and "streak artifacts" is shown in table II,III and IV. An 85.7% observer agreement was present in terms of overall image quality and streak artifacts. Similarly, an 92.85% observer agreement was present in terms of image noise.

Table II: Agreement for overall image quality

	Count	Rater 2			
		Worst (1)	Almost the same (2)	Best (3)	Total
Rater 1	Worst (1)	8	2	0	10
	Almost the same (2)	0	3	0	3
	Best (3)	0	0	1	1
	Total	8	5	1	14

Table III: Agreement for image noise

	Count	Rater 2			
		Worst (1)	Almost the same (2)	Best (3)	Total
Rater 1	Worst (1)	6	1	0	7
	Almost the same (2)	0	6	0	6
	Best (3)	0	0	1	1
	Total	6	7	1	14

Table III: Agreement for streak artifacts

	Count	Rater 2			
		Worst (1)	Almost the same (2)	Best (3)	Total
Rater 1	Worst (1)	8	0	0	8
	Almost the same (2)	2	4	0	6
	Best (3)	0	0	0	0
	Total	10	4	0	14

DISCUSSION

There are many studies reported in literature related to dose reduction techniques. However, trying to reduce the dose results in greater image noise. The advances in CT scanners has resulted in the production of good quality images with low radiation doses. The various techniques to reduce dose include dose modulation techiques, usage of appropriate filters that reduce noise and various iterative reconstruction techniques. Some studies reported that using dose modulation can reduce the dose by ~ 60 %. (15-16). Also, some studies have reported a superior spatial resolution and a better image quality using a larger image matrix (1024 x 1024; 2048 x 2048) compared to standard 512 x 512 matrix size (12,17). However, this method is for assessing the lungs. The present study aimed to evaluate the effect of low kilo-voltage and matrix size on radiation dose and image-quality, respectively for abdominopelvic computed tomography. The present study result showed that there was an increase in SNR and CNR at 120 kVp when increasing the matrix size from 512 to 1024. Akinori H et al. conducted a similar study showing an improvement in diagnostic quality of image using larger matrix size despite the increase in noise. However this study was done to assess the lung diseases (12,17). When using a larger matrix size for a given FOV, the sizes of the individual pixel is less resulting in increased noise and enhanced resolution. However, with the introduction of advanced iterative reconstruction techniques, this relationship between pixel size and noise is more complex (18). The present study also demonstrated that using a kVp of 140 and a matrix size of 512 x 512 & 768 x 768 showed higher values of SNR (22.6%,17.27%) and CNR (76.5,67.6%) compared to the standard 120 kVp and 512 x 512 matrix size.

Similarly, a combination of a 100 kVp with a larger matrix size of 768 x 768 reported better CNR (47%) compared to the reference. Increasing the matrix size to 1024 x 1024 resulted in a better SNR (2.1%). The increase in CNR can be attributed to the decrease in kVp as attenuation increases with decreased energy of x-ray beam. The increase in SNR could be due to the rise in mAs to compensate for decrease in kVp for reducing noise or due to the advances in hybrid iterative reconstruction techniques capable of reducing the noise as reported in some studies (18, 19, and 20). Further increasing the matrix size showed a slightly higher SNR but less CNR compared to the 120 kVp and 512 x 512 matrix size.

However, the research conducted by Godoy et al. implied that although noise is higher for low kVp images, the subjective quality is also higher for these images (21). In the subjective analysis, 120 kVp with 768 x 768 matrix size depicted improvement in terms of "overall image quality", "image noise" and scored equally in terms of "streak artifacts". Similarly, a combination of 100 kVp and 768 x 768 matrix size also scored similar performance in terms of image quality, noise and streak artifacts when compared to the standard 120 kVp and 512 x 512 matrix size.

The present study also reported a decrease in radiation dose as kVp decreased from 120 to 100, 80 and 70. Although the mA/mAs was constant for both 80 and 70 kVp, the decrease in dose could be as a result of using a lower kVp. Similarly, the study also observed a decrease in radiation dose using 140 kVp. This decrease in radiation dose can be explained by the 10 kVp or 15 % rule that states that increasing the kVp allows for the mAs to be halved thereby decreasing the dose (22). A lot of studies published in literature show a high kVp and low mAs technique help in effectively reducing the radiation dose (23-25). This complicated association between kVp, radiation-dose and quality of image is seen and therefore, kVp selection should be according to the patient size and procedure. Higher voltages can be useful for imaging obese patients. However, in CT examinations that use iodinated contrast media such as contrast enhanced computed tomography (CECT) abdomen and pelvis, there is a better enhancement of iodine using lower kVp. Therefore according to our study, lower kVp and larger matrix size can result in an optimum quality image with decrease radiation dose for CT abdominopelvic scans. However, the drawback of using larger matrix size is that the data size is much larger than a standard 512 x 512 matrix size (12) , but future advances in technology can resolve this. One of the limitation of the study is that due to the unavailability of ACR/ catphan ® phantom, the study was conducted on a PMMA phantom. Prospective clinical studies are required to further evaluate the usefulness of our results.

Secondly, the iDose4 iterative reconstruction technique was used for the study and it would be recommended to utilize other techniques such as model based iterative reconstruction (MIBR) or hybrid reconstruction to evaluate the variation in results. As the main objective of the study was to test if an increase in matrix size improve the image quality when trying to reduce the dose, the study utilised the automatic tube current modulation to optimise the increase in noise due to the decreased kVp. So further studies can be conducted using a constant tube current as well. Moreover, the research was done only on one machine, and the differences in manufacture and model can affect the outcome.

CONCLUSION

In conclusion, the study reported that a higher matrix size resulted in better SNR and CNR for 120 kVp. A combination of 100 kVp and 768 x 768 matrix size resulted in an improved CNR, similar SNR and less radiation dose for CT abdomen and pelvis compared to the reference protocol. In the subjective analysis, 768 x 768 matrix size with 120 kVp performed better with regards to overall image quality and noise, whereas 768 x 768 matrix size with 100 kVp showed similar performance in all categories.

ACKNOWLEDGEMENT

The authors would like to thank Kasturba hospital and Manipal College of health professions for their constant support in undertaking this study. We also extend our sincere gratitude to the Head of the department of Radio-diagnosis and imaging their cooperation in this phantom- study.

REFERENCES

1. 1. Brenner DJ, Hall EJ. Current concepts - Computed tomography - An increasing source of radiation exposure. New England Journal of Medicine. 2007; 357:2277-2284.
2. Sulieman A, Adam H, Elnour A, Tamam A, Alhaili A, et al. Patient radiation dose reduction using a commercial iterative reconstruction technique package. Radiation Physics and chemistry. 2021; 178:108996; 1-7
3. Almohiy H. Paediatric computed tomography radiation dose: A review of the global dilemma. World Journal of Radiology. 2014; 6(1):1-6.
4. Booij R, Budde R, Dijkshoorn M, Straten M. Technological developments of x-ray computed tomography over half a century: user's influence on protocol optimization. European journal of radiology.2020;131(109261):1-11
5. Guite KM, Hinshaw JL, Ranallo FN, Lindstrom MJ, Lee FT Jr. Ionizing radiation in abdominal CT: unindicated multiphase scans are an important source of medically unnecessary exposure. J Am Coll Radiol. 2011 Nov;8(11):756-61
6. Kayyum A, Panakkal N C, John A M. Evaluation of effective dose and associated radiation risks in common computed tomography procedures. Indian journal of public health research and development. 2020;11(3): 460-465
7. Brix G, Nissen-Meyer S, Lechel U, Nissen-Meyer J, Griebel J, Nekolla EA, et al. Radiation exposures of cancer patients from medical X-rays: how relevant are they for individual patients and population exposure? Eur J Radiol. 2009 Nov;72(2):342-7
8. Yamashita, K, Higashino, K, Hayashi H, Takegami, K, Hayashi, F, et al. Direct measurement of radiation exposure dose to individual organs during diagnostic computed tomography examination. Sci Rep 11, 5435 2021. [doi: 10.1038/s41598-021-85060-5]
9. Van der Molen AJ, Joemai RM, Geleijns J. Performance of longitudinal and volumetric tube current modulation in a 64-slice CT with different choices of acquisition and reconstruction parameters. Phys Med. 2012 Oct;28(4):319-26
10. Solomon J.B, Li X, Samei E, Relating Noise to image quality indicators in CTexaminations with tube current modulation. AJR Am. J. Roentgenol.2013; 200(3):592–600.
11. Wang J, Fleishcmann D. Improving spatial resolution at CT: Development ,benefits and pitfalls. Radiology.2018; 289 (1): 261-262.
12. Hata A, Yanagawa M, Honda O, Kikuchi N, Miyata T, Tsukagoshi S, et al. Effect of Matrix Size on the Image Quality of Ultra-high-resolution CT of the Lung: Comparison of 512Ч512, 1024Ч1024, and 2048x2048. Acad Radiol. 2018 Jul;25(7):869-876
13. Chang, K.-P, Hsu T.-K, Lin W.-T.,Hsu, W.-L. Optimisation of dose and image quality in adult and pediatric computed tomography scans. Radiation Physics and Chemistry. 2017 140, 260–265.
14. Rosner B. Fundamentals of Biostatistics.7th edition. Boston: Brooks/Cole,Cengage Learning;2011
15. Sabarudin A, Mustafa Z, Nassir KM, Hamid HA, Sun Z. Radiation dose reduction in thoracic and abdomen-pelvic CT using tube current modulation: a phantom study. J Appl Clin Med Phys. 2014 Jan 8;16(1):5135.
16. Papadakis AE, Perisinakis K, Damilakis J. Automatic exposure control in CT: the effect of patient size, anatomical region and prescribed modulation strength on tube current and image quality. Eur Radiol. 2014 Oct;24(10):2520-31
17. Zhu H, Zhang L, Wang Y, Hamal P, You X, Mao H, et al. Improved image quality and diagnostic potential using ultra-high-resolution computed tomography of the lung with small scan FOV: A prospective study. PLoS One. 2017 Feb 23;12(2):e0172688
18. Kristen B. Aquilon Precision ultra-high resolution CT: Quantifying diagnostic image quality.2018. [https://global.medical.canon/publication/ct/2018WP_Aquilion_Precision_Ultra-High_Resolution]
19. Yanagawa M, Gyobu T, Leung AN, Kawai M, Kawata Y, Sumikawa H, et al. Ultra-low-dose CT of the lung: effect of iterative reconstruction techniques on image quality. Acad Radiol. 2014 Jun;21(6):695-703.
20. Pichardt PJ, Lubner MG, David H, Jie T, Julie A, Alejandro M, et al . Abdominal CT with model iterative reconstruction (MBIR):intial results of prospective trial comparing ultra-low dose with standard dose imaging.AJR Am J Roentgenol 2012;199:1266-1274.
21. Godoy MC, Samantha L, David P, Bernard

A, Christianne L, et al. Duel energy MDCT: Comparison of pulmonary artery enhancement on dedicated pulmonary angiography, routine and low contrast volume studies. Eur J Radiol.2011 79(2); E11-E17.

22. Nicole E, Adam L. An evaluation of the effect of tube potential on clinical image quality using direct digital detector for pelvis and lumbar spine radiographs. J med Radiat sci. 2020;67: 260-268.
23. Charnley C, England A, Martin A, Taylor S, Benson N,Jones L. An option for optimising the radiographic technique for horizontal beam lateral (HBL) hip radiography when using digital X-ray equipment.Radiography 2016; 22(2): e137–e142
24. Lorusso JR, Fitzgeorge L, Lorusso D, Lorusso E. Examining practitioners' assessments of perceived aestheticand diagnostic quality and high kVp-Low mAs pelvis,chest, skull, and hand phantom radiographs. J MedImaging Radiat Sci 2015; 46(2): 162–73
25. Barba J, Culp M. Copper Filtration and kVp: Effect on entrance skin exposure. Radiol Technol 2015;46(2):162-73